

Can Wood be used as a Bio-mechanical Substitute for Bone during Evaluation of Surgical Machining Tools?

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It is often not possible to machine human or animal tissue, such as bone, in a typical engineering workshop due to the numerous health risks associated. Further to this, currently used synthetic substitutes are also unsuitable for machining. This is mainly due to the aerosolization of harmful particles created during the machining process. It is however essential to thoroughly test and evaluate emerging orthopedic cutting tool designs, particularly when considering that osteonecrosis occurs at as low as 47 °C cutting temperature. It is proposed here that a composite bone model can be constructed using a dense hardwood to represent the hard cortical bone outer shell, and a less dense softwood to represent the spongy cancellous bone interior.

Keywords: Cortical bone; Cancellous bone; Polyurethane foam; Glass fiber reinforced epoxy

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Background

Like wood, bone is a heterogeneous anisotropic material. It consists of a hard, dense outer layer known as cortical bone with a soft, spongy interior known as cancellous bone. The cortical bone outer layer is composed of osteons, the longitudinal building blocks that provide bone its great strength and rigidity. Cancellous bone, on the other hand, is less dense and is composed of porous osseous tissue.

Due to the health risks associated with human and animal tissue, it is rarely permitted to machine bone in a typical workshop. It is however vital that engineers can evaluate the suitability of the cutting tools before they are approved for use by surgeons. It is of particular importance that the temperature induced during cutting does not exceed 47 °C, the threshold temperature for osteonecrosis (death of bone tissue) (Eriksson *et al.* 1984). To address these issues, biomechanical test blocks are often used to simulate bone. These test blocks can be separated into two typical categories: 1) Solid polyurethane foam of varying density used to simulate both cortical and cancellous bone (Patel *et al.* 2008); 2) Glass fiber reinforced epoxy (GFRE) used to simulate cortical bone only (Chong *et al.* 2007). Both of these materials have their limitations. The former is homogenous and hence does not reflect the longitudinal grain structure of cortical bone; it is not advisable to machine the latter in a typical workshop, as this aerosolizes the glass fiber particles, introducing the risk of respiratory inflammation to anyone within close proximity.

Comparison of Properties

The properties of polyurethane foam are poorly matched to those of bone, with the exception of thermal conductivity for high-density cancellous bone (Table 1). The properties of glass fiber reinforced epoxy are in fact very well aligned to those of cortical bone, both along and across the grain. This makes it the ideal material for mechanical tests, yet machinability is still problematic due to the aerosolization of glass fiber particles.

When focusing on wood (Table 2) it is evident that the properties of the higher density, hardwood species (oak and *Lignum vitae*) are well aligned with cortical bone. The properties of the softwood species (pine and spruce), obtained through testing across the grain only, are more comparable to cancellous bone. It is therefore possible to construct a bio-mechanical test block using a thin layer of hardwood cemented to a thicker layer of softwood. In this instance, the wood grain direction of the hardwood layer should be oriented longitudinally to mimic the osteons present in cortical bone. The grain direction of the softwood layer should be perpendicular to that of hardwood to account for the disparity in properties along and across the grain, as properties taken across the grain only are comparable to high density cancellous bone.

Table 1. Properties of Bone and Biomechanical Test Substitutes

	Cortical Bone (Along grain)	Cortical Bone (Across Grain)	Cancellous Bone (High Density)	Cancellous Bone (Low Density)	Polyurethane foam (Medium Density)	GFRE (Along Grain)	GFRE (Across Grain)
Density (Kg/m ³)	1800-2000	1800-2000	700-975	300-550	1120 - 1240	1750-1970	1750-1970
Elastic Modulus (GPa)	18-26	10-13	0.8-1.5	0.07-0.4	1.31-1.37	15-28	2.35-3.08
Tensile Strength (MPa)	135-167	49-60	6-12	2-3	31-62	138-241	45-89.6
Flexural Modulus (GPa)	14-22.6	14-22.6	0.8-1.5	0.07-0.4	1.31-2.07	16.5-30.8	2.35-3.08
Flexural Strength (MPa)	150-180	50-65	6-12	2-3	31-62	124-217	45-89.6
Shear Modulus (GPa)	4.5-6.7	3.3-4	0.3-0.5	0.03-0.15	0.465-0.735	6-11	0.84-1.1
Thermal Conductivity (W/m.K)	0.41-0.63	0.41-0.63	0.2-0.31	0.12-0.19	0.235-0.244	0.4-0.55	0.4-0.55
Specific Heat Capacity (J/Kg.K)	1100-1260	1100-1260	1100-1260	1100-1260	1550-1620	1000-1200	1000-1200

Table 2. Properties of Selected Woods

	Oak (Along grain)	Oak (Across grain)	<i>Lignum vitae</i> (Along grain)	<i>Lignum vitae</i> (Across grain)	Pine (Along Grain)	Pine (Across Grain)	Spruce (Along Grain)	Spruce (Across Grain)
Density (Kg/m³)	850-1030	850-1030	1110-1350	1110-1350	440-600	440-600	450-560	450-560
Elastic Modulus (GPa)	20.6-25.2	4.5-5.8	22.1-27.8	11.2-12.5	8.4-10.3	0.6-0.9	14.3-17.4	0.8-0.89
Tensile Strength (MPa)	132-162	7.1-8.7	133-162	7.2-8.8	60-100	3.2-3.9	76.5-93.5	2.5-3.1
Flexural Modulus (GPa)	20.6-25.2	4.5-5.8	22.1-27.8	11.2-12.5	8.4-10.3	0.6-0.9	14.3-17.4	0.8-0.89
Flexural Strength (MPa)	132-162	7.1-8.7	135-180	7.2-8.8	60-100	3.2-3.9	70.2-85.8	2.5-3.1
Shear Modulus (GPa)	1.5-1.8	1.5-1.8	0.9-1.1	1.15-1.58	0.62-0.72	0.35-0.4	1.06-1.29	0.083-0.11
Thermal Conductivity (W/m.K)	0.41-0.5	0.41-0.5	0.54-0.66	0.54-0.66	0.22-0.3	0.22-0.3	0.22-0.27	0.22-0.27
Specific Heat Capacity (J/Kg.K)	1200-2300	1200-2300	1200-2300	1200-2300	1200-2300	1200-2300	1200-2300	1200-2300

Proposed Further Developments

The proposed wooden bio-mechanical test block is certainly a more promising option than using polyurethane foam to simulate bone. Properties are much closer aligned, and like bone, wood is a heterogeneous anisotropic material. The proposed test block, however, would not be able to match the properties of bone as well as Glass fiber reinforced epoxy. It can however be machined with much fewer associated health risks. To summarize, the proposed test block can provide a much safer, inexpensive solution to machining bone in a typical workshop environment. It is the intention of the author to validate this hypothesis through a program of controlled cutting tests.

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